

7/PATS

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**Alkoxyamines Resulting From β -Phosphorated Nitroxides And Their Use In
Radical Polymerization**

TECHNICAL FIELD

[0001] A subject-matter of the present invention is α,β,β -trisubstituted hydroxylamines, hereafter denoted by alkoxyamines, obtained in particular from β -phosphorated nitroxides, which can be used as initiators for radical polymerizations.

PRIOR ART

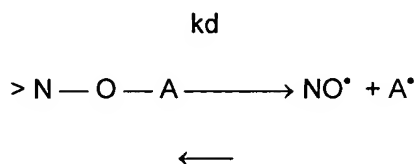
[0002] FR 2 789 991 A1 discloses alkoxyamines resulting from β -phosphorated nitroxides, such as N-(tert-butyl)-N-(1-diethoxyphosphoryl-2,2-dimethylpropyl)-O-(1-methyl-1-(methoxycarbonyl)ethyl)hydroxylamine, which, used as initiators for polymerizations or copolymerizations of at least one monomer which can be polymerized by the radical route, provide excellent control of the polydispersity while ensuring a good rate of polymerization or of copolymerization.

[0003] However, the Applicant Company has found that there were some disadvantages to the use of the said alkoxyamines in the polymerization or the copolymerization of certain monomers which can be polymerized by the radical route.

[0004] Thus, it is difficult to achieve high molar masses. In addition, risks of runaway of the polymerization are observed with monomers having high propagation constants (k_p), such as certain acrylates, when these initiators are used alone.

[0005] Without the Applicant Company being committed to any one explanation, it believes that, at the very start of the initiation of the polymerization of monomers having high k_p values, in the presence of the said alkoxyamines, there is production of R^\bullet hydrocarbonaceous radicals which propagate very quickly to result in very high masses. This initial propagation reaction is very exothermic and runaway of the radical

polymerization occurs. The persistent nitroxide radical $>\text{NO}^\bullet$, formed from the homolytic cleavage of an alkoxyamine $>\text{N} - \text{O} - \text{A}$ according to the reaction scheme:



with an excessively low kinetic dissociation constant k_d with respect to k_p , can no longer control the polymerization reaction as it is found to be in an insufficient concentration to control the growth of the chains and thus the evolution of heat.

[0010] In order to overcome this disadvantage, some authors have added, at the beginning of polymerization, in addition to the alkoxyamine, a nitroxide (D. Benoit et al., J. Am. Chem. Soc., 121, pages 3904-3920, 1999).

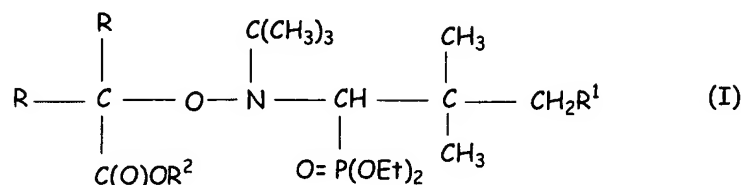
[0011] It is unsatisfactory to proceed in this way industrially as the alkoxyamine/nitroxide ratio has to be constantly adjusted to the type of monomer or mixture of monomers to be polymerized and to the polymerization temperature.

[0012] Furthermore, it is very difficult, when using the said alkoxyamines, to control the polymerization of alkyl methacrylates, such as methyl methacrylate (MMA), or the copolymerization of mixtures of monomers comprising high proportions of alkyl methacrylates.

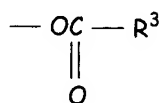
ACCOUNT OF THE INVENTION

[0013] The Applicant Company has now found that the use of certain alkoxyamines derived in particular from β -phosphorated nitroxides as initiators for polymerizations or copolymerizations of at least one monomer which can be polymerized by the radical route makes it possible to overcome the abovementioned disadvantages.

[0014] A subject-matter of the invention is thus the use of alkoxyamines of formula:



in which R represents a linear or branched alkyl radical having a number of carbon atoms ranging from 1 to 3, R¹ represents a hydrogen atom or a residue:



in which R³ represents a linear or branched alkyl radical having a number of carbon atoms ranging from 1 to 20, and R² represents a hydrogen atom, a linear or branched alkyl radical having a number of carbon atoms ranging from 1 to 8, a phenyl radical, an alkali metal, such as Li, Na or K, H₄N⁺, Bu₄N⁺ or Bu₃HN⁺, exhibiting a kinetic dissociation constant k_d, measured at 120°C by EPR, of greater than 0.05 s⁻¹ and preferably of greater than 0.1 s⁻¹.

[0015] It is preferable, among the alkoxyamines of formula (I), to use very particularly those in which R = CH₃-, R¹ = H and R² = H, CH₃-, (CH₃)₃C-, Li and Na.

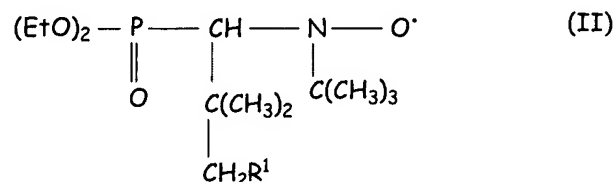
[0016] The alkoxyamines of formula (I) in which R¹ = H and R² represents a linear or branched alkyl radical having a number of carbon atoms ranging from 1 to 6 are known.

[0017] Another subject-matter of the invention is thus the alkoxyamines of formula (I), with the exception of the alkoxyamines of formula (I) in which R¹ = H and R² represents a linear or branched alkyl radical having a number of carbon atoms ranging from 1 to 6.

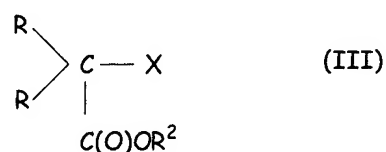
[0018] The alkoxyamines of formula (I) can be prepared according to methods known in the literature. The commonest method involves the coupling of a carbonaceous radical with a nitroxide radical.

[0019] Use will preferably be made, among all these methods, for the preparation of the compounds of formula (I), of the method involving the ATRA (Atom Transfer Radical Addition) reaction, as disclosed in FR 2 791 979 A1 incorporated in the present document by reference.

[0020] This method consists in reacting a nitroxide of formula:



with a halogenated derivative of formula:



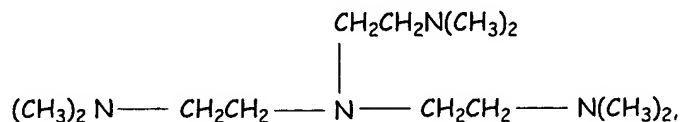
[0021] in which X represents a chlorine atom or a bromine atom, R, R¹ and R² having the same meanings as in the formula (I), in a water-immiscible organic solvent medium in the presence of an organometallic system MA(L)_n (IV) in which:

M represents a metal, such as Cu, Ag and/or Au and preferably Cu,

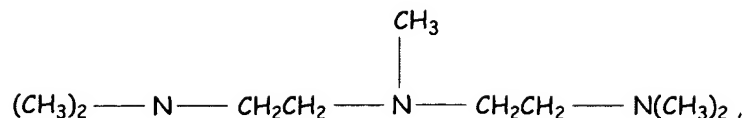
A represents a chlorine atom or a bromine atom,

L represents a ligand of the metal M and is chosen from polyamines, such as:

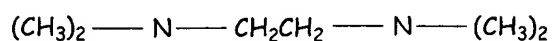
- tris[2-(dimethylamino)ethyl]amine:



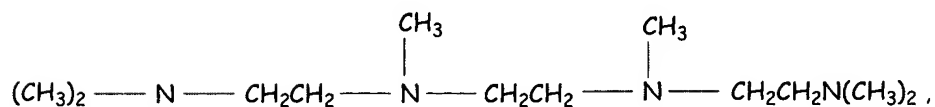
- N,N,N',N',N''-pentamethyldiethylenetriamine (PMDETA):



- N,N,N',N'-tetramethylethylenediamine:



- 1,1,4,7,10,10-hexamethyltriethylenetetramine (HMTETA):



[0022] cyclic polyamines, such as:

- 1,4,7-trimethyl-1,4,7-triazacyclononane,
- 1,5,9-trimethyl-1,5,9-triazacyclododecane,
- 1,4,8,11-tetramethyl-1,4,8,11-tetraazacyclotetradecane,

[0023] by mixing a metal salt MA, the ligand L, the halogenated derivative (III) and the nitroxide (II) according to a molar ratio (III)/(II) ranging from 1 to 1.4 with stirring in the organic solvent and by keeping the reaction medium stirred at a temperature of between 20°C and 40°C until the nitroxide (II) has completely disappeared, by then recovering the organic phase, which is washed with water, and by then isolating the alkoxyamine (I) by evaporation of the organic solvent under reduced pressure.

[0024] Use will preferably be made, as organic solvents, of aromatic hydrocarbons, such as benzene, toluene, xylenes, alkyl chlorides, and in particular CH_2Cl , and/or ethers.

[0025] The metal salt used is preferably CuBr.

[0026] It is also possible to introduce CuBr (in which the copper is in the 1 oxidation stage) and copper into the reaction medium.

[0027] The alkali metal salts of the alkoxyamines (I) ($R^2 = \text{Li, Na, K}$) can be easily obtained, for example by dissolving, under cold conditions, the alkoxyamine (I) in the acid form ($R^2 = \text{H}$) in the minimum amount of methanol and then adding 1.05 equivalents of alkali metal hydroxide in the minimum amount of water. The water/methanol mixture is evaporated under reduced pressure and the remaining water is removed azeotropically using cyclohexane or benzene.

[0028] The alkoxyamines of formula (I) according to the present invention can be used for the polymerization and the copolymerization of any monomer exhibiting a carbon-carbon double bond capable of polymerizing by the radical route. The polymerization or the copolymerization is carried out under the usual conditions known to a person skilled in the art taking into account the monomer or monomers under consideration, under bulk, solution, emulsion, suspension or miniemulsion conditions. The monomers under consideration can be chosen from vinylaromatic monomers, such as styrene or substituted styrenes, in particular α -methylstyrene and sodium styrenesulphonate, dienes, such as butadiene or isoprene, acrylic monomers, such as acrylic acid or its salts, alkyl, cycloalkyl or aryl acrylates, such as methyl, ethyl, butyl, ethylhexyl or phenyl acrylates, hydroxyalkyl acrylates, such as 2-hydroxyethyl acrylate, ether alkyl acrylates, such as 2-methoxyethyl acrylate, alkoxy- or aryloxypolyoxyalkylene glycol acrylates, such as methoxypolyethylene glycol acrylates, ethoxypolyethylene glycol acrylates, methoxypolypropylene glycol acrylates, methoxypolyethylene glycol-polypropylene glycol acrylates or their mixtures, aminoalkyl acrylates, such as 2-(dimethylamino)ethyl acrylate (ADAME), acrylates of amine salts, such as [2-(acryloyloxy)ethyl]trimethylammonium chloride or sulphate or [2-(acryloyloxy)ethyl]dimethylbenzylammonium chloride or sulphate, fluoroacrylates, silylated acrylates or phosphorus-comprising acrylates, such as alkylene glycol acrylate

phosphates, methacrylic monomers, such as methacrylic acid or its salts, alkyl, cycloalkyl, alkenyl or aryl methacrylates, such as methyl, lauryl, cyclohexyl, allyl or phenyl methacrylate, hydroxyalkyl methacrylates, such as 2-hydroxyethyl methacrylate or 2-hydroxypropyl methacrylate, ether alkyl methacrylates, such as 2-ethoxyethyl methacrylate, alkoxy- or aryloxypolyalkylene glycol methacrylates, such as methoxypolyethylene glycol methacrylates, ethoxypolyethylene glycol methacrylates, methoxypolypropylene glycol methacrylates, methoxypolyethylene glycol-polypropylene glycol methacrylates or their mixtures, aminoalkyl methacrylates, such as 2-(dimethylamino)ethyl methacrylate (MADAME), methacrylates of amine salts, such as [2-(methacryloyloxy)ethyl]trimethylammonium chloride or sulphate or [2-(methacryloyloxy)ethyl]dimethylbenzylammonium chloride or sulphate, fluoromethacrylates, such as 2,2,2-trifluoroethyl methacrylate, silylated methacrylates, such as 3-methacryloyloxypropyltrimethylsilane, phosphorus-comprising methacrylates, such as alkylene glycol methacrylate phosphates, hydroxyethylimidazolidone methacrylate, hydroxyethylimidazolidinone methacrylate or 2-(2-oxo-1-imidazolidinyl)ethyl methacrylate, acrylonitrile, acrylamide or substituted acrylamides, 4-acryloylmorpholine, N-methylolacrylamide, acrylamidopropyltrimethylammonium chloride (APTAC), acrylamidomethylpropanesulphonic acid (AMPS) or its salts, methacrylamide or substituted methacrylamides, N-methylolmethacrylamide, methacrylamidopropyltrimethylammonium chloride (MAPTAC), itaconic acid, maleic acid or its salts, maleic anhydride, alkyl or alkoxy- or aryloxypolyalkylene glycol maleates or hemimaleates, vinylpyridine, vinylpyrrolidinone, (alkoxy)poly(alkylene glycol) vinyl ethers or divinyl ethers, such as methoxypoly(ethylene glycol) vinyl ether or poly(ethylene glycol) divinyl ether, alone or as a mixture of at least two abovementioned monomers.

[0029] The alkoxyamines (I) can be introduced into the polymerization or copolymerization medium at contents generally ranging from 0.005% to 40% by weight

with respect to the monomer(s) employed and, preferably, at contents ranging from 0.01% to 10%.

[0030] Another subject-matter of the invention is therefore the functional (co)polymers obtained by a (co)polymerization process using the alkoxyamines of formula (I) as initiators.

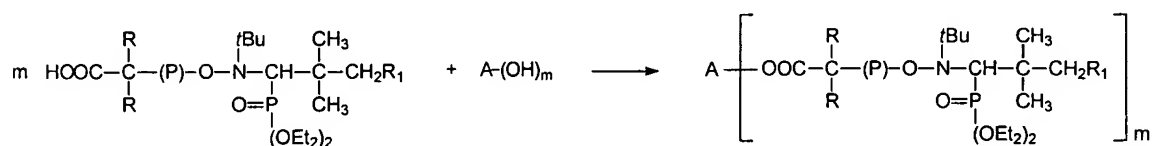
[0031] There are numerous advantages to the use of the alkoxyamines (I) of the invention.

[0032] They make it possible to obtain high molar masses with good control and a low polydispersity index. No runaway of the polymerization is observed, in particular in the case of monomers with a high k_p , such as butyl acrylate, this being the case in the absence of free nitroxide. They make possible (partial) control of the polymerization of alkyl methacrylates, such as MMA, in particular in the case of a mixture of monomers comprising at least 85% of alkyl methacrylate.

[0033] In the case where R^2 is a hydrogen, an alkali metal or a tert-butyl radical, they also make it possible to obtain functional (co)polymers exhibiting reactive functional groups which make it possible to carry out chemical conversions, such as grafting or coupling.

[0034] These chemical conversion processes preferably involve esterification, transesterification, amidation, transamidation and epoxide opening reactions. It would not be departing from the scope of the invention if an acid chloride were used as intermediate in the esterification or amidation reactions.

[0035] Esterification processes can in particular be advantageously used for preparing polymeric polyalkoxyamines from polymeric monoalkoxyamines according to the following scheme:



[0036] where A represents a polyvalent structure and P a sequence of monomers, such as styrene and substituted styrenes, dienes, acrylic monomers, such as acrylic acid or alkyl acrylates, methacrylic monomers, such as methacrylic acid or alkyl methacrylates, acrylonitrile, acrylamide, vinylpyrrolidinone or a mixture of at least two abovementioned monomers.

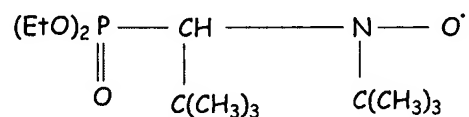
[0037] Esterification and amidation processes can also be advantageously used for condensing polymers which are not obtained by radical polymerization, such as polyesters, polyamides or polyepoxides. These reactions thus make possible access to multiple block copolymer structures, such as polystyrene-polyester, polystyrene-polyamide, polystyrene-polyepoxide, polyacrylate-polyester, polyacrylate-polyamide or polyacrylate- polyepoxide.

[0038] The alkoxyamines of formula (I) of the present invention additionally exhibit the advantage of being stable solids which can be easily purified. Without the Applicant Company being committed to any one explanation, it is believed that this state results from the fact that, in the alkoxyamine of formula (I), the carbon carrying the R and R² radicals is not asymmetric, in contrast to the epoxyamines mentioned in FR 2 789 991 A1.

[0039] The examples which follow illustrate the invention.

GENERAL COMMENTS:

- The nitroxide used as reactant has the formula:



hereinafter denoted SG1.

[0040] It was obtained by oxidation of diethyl 2,2-dimethyl-1-(1,1-dimethylamino)propylphosphonate with peracetic acid according to a protocol disclosed in FR 2 788 270.

- The compounds obtained in the synthetic examples are identified by C, H and N microanalysis and by ^1H , ^{13}C and ^{31}P NMR.

[0041] The NMR spectra were recorded on a Bruker AC 400 device (^1H , 100 MHz; ^{31}P , 40.53 MHz; ^{13}C , 25.18 MHz). ^{13}C and ^{31}P NMR spectra are produced with ^1H decoupling.

[0042] The chemical shifts δ are given in ppm, with respect to tetramethylsilane (internal reference) for ^1H and ^{13}C and with respect to 85% H_3PO_4 (external reference) for ^{31}P .

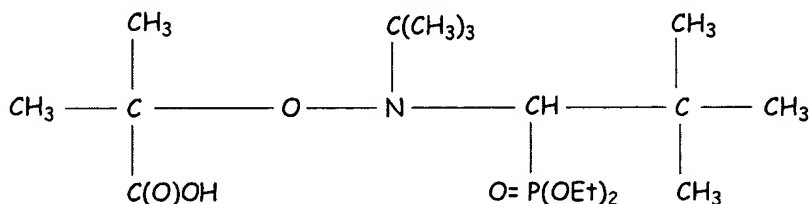
[0043] The solvents used are either CDCl_3 or C_6D_6 .

- The kinetic dissociation constants k_d were measured at 120°C by quantitative electron paramagnetic resonance (EPR) according to the method described by Sylvain Marque et al. in *Macromolecules*, 33, pages 4403 to 4410, 2000.

[0044] The principle consists in completely and rapidly trapping, as soon as it is formed, the transitory hydrocarbonaceous radical with a nitroxide, such as galvinoxyl (2,6-di(tert-butyl)-4-(3,5-di(tert-butyl)-4-oxocyclohexa-2,5-dien-1-ylidenmethyl)phenoxy), to result in another unreactive alkoxyamine.

[0045] **Example 1:**

[0046] Preparation of 2-methyl-2-[N-(tert-butyl)-N-(diethoxyphosphoryl-2,2-dimethylpropyl)aminoxy]propionic acid



[0047] **Procedure:**

[0048] 500 ml of degassed toluene, 35.9 g of CuBr (250 mmol), 15.9 g of copper powder (250 mmol) and 86.7 g of N,N,N',N',N''-pentamethyldiethylenetriamine (PMDETA) (500 mmol) are introduced into a 2 l glass reactor purged with nitrogen and then a mixture

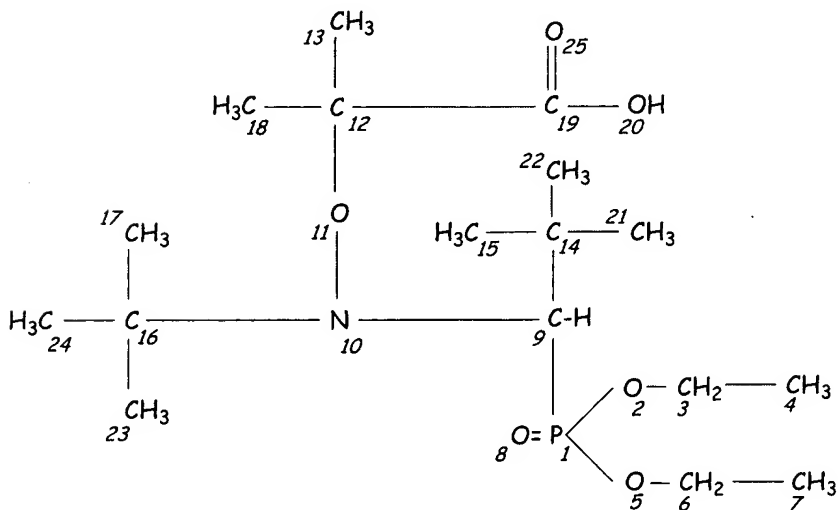
comprising 500 ml of degassed toluene, 42.1 g of 2-bromo-2-methylpropionic acid (250 mmol) and 78.9 g of 84% SG1, i.e. 225 mmol, is introduced with stirring and at ambient temperature (20°C).

[0049] The reaction medium is allowed to react at ambient temperature for 90 minutes and with stirring and is then filtered. The toluene filtrate is washed twice with 1.5 l of a saturated aqueous NH_4Cl solution.

[0050] A yellowish solid is obtained, which solid is washed with pentane to give 51 g of 2-methyl-2-[N-(tert-butyl)-N-(diethoxyphosphoryl-2,2-dimethylpropyl)aminoxy]propionic acid (60% yield).

[0051] The analytical results are given below:

- molar mass, determined by mass spectrometry: $381.44 \text{ g.mol}^{-1}$
(for $\text{C}_{17}\text{H}_{36}\text{NO}_6\text{P}$)
- elemental analysis (empirical formula: $\text{C}_{17}\text{H}_{36}\text{NO}_6\text{P}$):
% calculated: C = 53.53, H = 9.51, N = 3.67
% found: C = 53.57, H = 9.28, N = 3.77
- melting determined on a Büchi B-540 device: 124°C-125°C



- ^{31}P NMR (CDCl_3): δ 27.7
- ^1H NMR (CDCl_3):
 - δ 1.15 (singlet, 9H on carbons 15, 21 and 22),
 - δ 1.24 (singlet, 9H on carbons 17, 23 and 24),
 - δ 1.33-1.36 (multiplet, 6H on carbons 4 and 7),
 - δ 1.61 (multiplet, 3H on carbon 18),
 - δ 1.78 (multiplet, 3H on carbon 13),
 - δ 3.41 (doublet, 1H on carbon 9),
 - δ 3.98-4.98 (multiplet, 4H on carbons 3 and 6)
 - δ 11.8 (singlet, $-\text{OH}$).
- ^{13}C NMR (CDCl_3):

Carbon atom No.	δ
3 and 6	60.28 – 63.32
9	69.86
12	63
13	28.51
14	36.04
15, 21 and 22	29.75
16	63.31
17, 23 and 24	28.74
18	24.08
19	176.70

$$k_d (120^\circ\text{C}) = 0.2 \text{ s}^{-1}.$$

[0090] **Examples 1A and 1B:**

[0091] Synthesis of alkyl 2-methyl-2-[N-(tert-butyl)-N-(1-diethoxyphosphoryl-2,2-dimethylpropyl)aminoxy]propionates

[0092] **Procedure:**

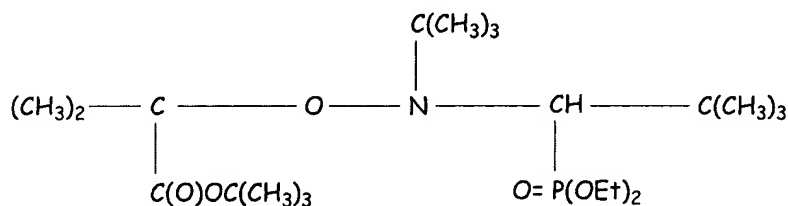
[0093] Cuprous bromide CuBr, copper Cu(0) and anhydrous benzene are placed in a round-bottomed flask equipped with a septum. The solution is subsequently deoxygenated by sparging with nitrogen for 10 minutes. N,N,N',N',N''-Pentamethyldiethylenetriamine

(PMDETA) is subsequently introduced under an inert atmosphere. Sparging with nitrogen is maintained for an additional 10 minutes.

[0094] The α -brominated ester and the nitroxide SG1 are placed in anhydrous benzene in another round-bottomed flask. The solution is also degassed by sparging with nitrogen for 10 minutes. This solution is subsequently transferred into the first round-bottomed flask under an inert atmosphere. The reaction mixture, cooled using a water/ice mixture, is kept stirred magnetically for 15 min and then at ambient temperature for 45 min. The solution is subsequently filtered through celite and the precipitate is washed with ether. The filtrate is washed with ice-cold water until a colourless aqueous phase is obtained. The organic phase is dried over MgSO_4 at 0°C and evaporated, to start with on a Rotavapor rotor evaporator and then on a 0.08 mbar reduced pressure line.

[0095] **Example 1A:**

[0096] Synthesis of tert-butyl 2-methyl-2-[N-(tert-butyl)-N-(1-diethoxyphosphoryl-2,2-dimethylpropyl)aminoxy]propionate



[0097] *Reactants:* Benzene (18 ml + 18 ml), CuBr: 1.47 g (10.2 mmol), Cu(0): 0.65 g (10.2 mmol), PMDETA: 4.3 ml (20.4 mmol), SG1: 2 g (6.8 mmol), tert-butyl 2-bromo-2-methylpropionate: 2.23 g (10.2 mmol). The alkoxyamine obtained is purified on a silica column using a 3/1 pentane/ethyl ether mixture as eluent. The alkoxyamine solidifies at -18°C to give a white powder. Yield 70%.

[0098] k_d (120°C) = 0.2 s^{-1} .

[0099] Melting: $44\text{--}46^\circ\text{C}$

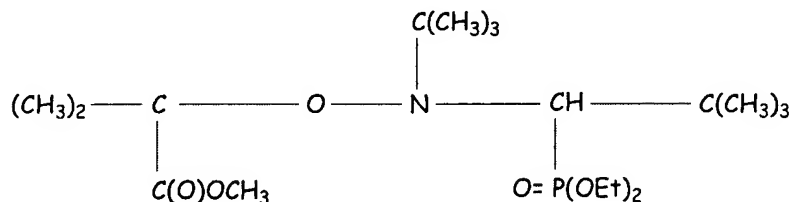
[00100] ^{31}P NMR (CDCl_3 , 121.59 MHz): δ 25.50 ppm.

[00101] ^1H NMR (CDCl_3 , 300 MHz): δ 1.12 ppm (s, 9H), 1.20 (s, 9H), 1.29 (m, 6H), 1.46 (s, 9H), 1.55 (s, 3H), 1.67 (s, 3H), 3.28 (d, $J_{\text{H-P}} = 27$ Hz, 1 H), 3.90-4.16 (m, 2H), 4.27-4.45 (m, 2H).

[00102] ^{13}C NMR (CDCl_3 , 75.48 MHz): δ 16.27 ppm (d, $J_{\text{C-P}} = 6.8$ Hz, $\text{O-CH}_2\text{-C(CH}_3\text{)}_3$), 16.65 (d, $J_{\text{C-P}} = 5.3$ Hz, $\text{O-CH}_2\text{-C(CH}_3\text{)}_3$), 22.01 (s, $\text{CH}_3\text{-C(CH}_3\text{)}_2\text{-C=O}$), 27.93 (s, t-Bu), 28.15 (s, t-Bu), 28.77 (s, $\text{CH}_3\text{-C(CH}_3\text{)}_2\text{-C=O}$), 30.18 (d, $J_{\text{C-P}} = 4.52$ Hz, $\text{CH-C(CH}_3\text{)}_3$), 36.00 (d, $J_{\text{C-P}} = 6.0$ Hz, $\text{CH-C(CH}_3\text{)}_3$), 58.62 (d, $J_{\text{C-P}} = 7.5$ Hz, $\text{O-CH}_2\text{-CH}_3$), 61.68 (d, $J_{\text{C-P}} = 6.0$ Hz, $\text{O-CH}_2\text{-CH}_3$), 62.08 (s, $\text{N-C(CH}_3\text{)}_3$), 69.93 (d, $J_{\text{C-P}} = 137.4$ Hz, CH-P), 80.81 (s, $\text{O-C(CH}_3\text{)}_3$), 84.41 (s, $(\text{CH}_3)_2\text{-C-C=O}$), 174.39 (s, C=O).

[00103] **Example 1B:**

[00104] Synthesis of methyl 2-methyl-2-[N-(tert-butyl)-N-(1-diethoxyphosphoryl-2,2-dimethylpropyl)aminoxy]propionate



[00105] Reactants: identical to Example 1A, except that tert-butyl 2-bromo-2-methylpropionate is replaced with the same molar amount of methyl 2-bromo-2-methylpropionate: (10.2 mmol).

[00106] The alkoxyamine is obtained without additional purification and solidifies at -18°C to give a white powder.

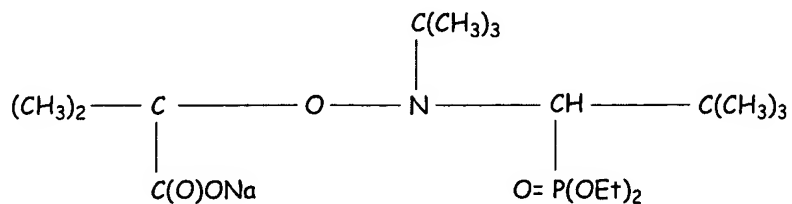
[00107] k_d (120°C) = 0.8 s^{-1} .

[00108] Melting: $56\text{-}58^\circ\text{C}$

[00109] ^{31}P , ^{13}C and ^1H NMR are in agreement with those mentioned in French Patent Application No. 2 789 991.

[00110] **Example 1C:**

[00111] Synthesis of sodium 2-methyl-2-[N-(tert-butyl)-N-(1-diethoxyphosphoryl-2,2-dimethylpropyl)aminoxy]propionate



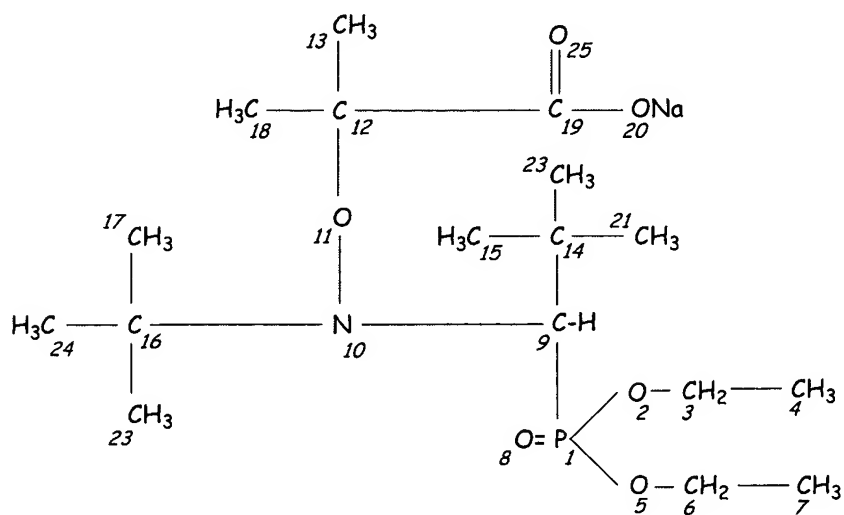
[00112] The methylpropionic acid/SG1 alkoxyamine obtained in Example 1 is dissolved in the minimum amount of methanol. 1.05 equivalents of sodium hydroxide, dissolved in the minimum amount of water, are then added thereto. The water/methanol mixture is evaporated under reduced pressure until the sodium salt is obtained, which salt exists in the form of a white solid. Cyclohexane is added in order to remove the traces of water by distillation of the water/cyclohexane azeotrope.

[00113] Elemental analysis (empirical formula $\text{C}_{17}\text{H}_{35}\text{NO}_6\text{PNa}$)

[00114] Percentage calculated: C = 50.61; H = 8.74; N = 3.47

[00115] Percentage found: C = 49.29; H = 8.97; N = 3.01

[00116] k_d (120°C) = 0.2 s⁻¹



- ^{31}P NMR (C_6D_6): δ 28.05

- ^1H NMR (C_6D_6):

δ 1.24-1.48 (unresolved peak, 24H on carbons 4, 7, 15, 17, 21 and 24),

δ 1.91 (singlet, 3H on carbon 18),

δ 2.07 (singlet, 3H on carbon 13),

δ 3.43 (doublet, 1H on carbon 9),

δ 4.15-4.6 (unresolved peak, 4H on carbons 3 and 6)

- ^{13}C NMR (C_6D_6):

Carbon atom No.	δ
3 and 6	61.33-61.42
4 and 7	16.55-16.70
9	71.08
12	86.36
13 and 18	24-29.10
14	36.24
15, 21 and 22	30.23
16	62.42
17, 23 and 24	29.27
19	180.74

[0090] **Examples 2, 3 and 4:**

[0091] Use of 2-methyl-2-[N-(tert-butyl)-N-(diethoxyphosphoryl)-2,2-dimethylpropyl]-aminoxylpropionic acid, hereinafter methy|propionic acid/SG1, as initiator in the polymerization of butyl acrylate

[0092] **General procedure:**

[0093] The introduction of x g of alkoxyamine and 60 g of butyl acrylate (BA) into a 100 ml glass reactor equipped with a reflux condenser, an inert gas (N_2) inlet and a temperature probe was carried out. The medium was degassed by sparging with nitrogen for 20 minutes and was then placed, under magnetic stirring, in an oil bath thermostatically controlled at 120°C. Samples were withdrawn under an inert atmosphere at regular time intervals.

[0094] Proton NMR allowed us to monitor the conversion of the monomer. The determination of the average molar masses of the polymer and of their polydispersity indices was carried out by steric exclusion chromatography (SEC), by virtue of a universal calibration using polystyrene standards and the Mark-Houwink coefficients of poly(butyl acrylate) in THF. The chromatograms were recorded with Millenium 32 software equipped with a Waters 515HPLC pump, a Waters 2410 refractometer and 3 Styragel columns (eluent: THF, 30°C).

[0095] **Example 2 (in accordance with the invention):**

- $x = 0.304$ g of methylpropionic acid/SG1 alkoxyamine obtained according to Example 1,
- the targeted theoretical mass Mn_{th} , expressed as being the ratio of the initial concentration of the monomer multiplied by the molar mass of the monomer to the initial concentration of alkoxyamine, at 100% conversion, is $75\,000\text{ g.mol}^{-1}$.

[0090] **Example 3 (in accordance with the invention):**

- $x = 0.114$ g of methylpropionic acid/SG1 alkoxyamine,
- $Mn_{th} = 200\,000\text{ g.mol}^{-1}$

[0090] **Example 4 (not in accordance with the invention):**

- $x = 0.114$ g of MONAMS, plus 2 mg of SG1

[0091] **MONAMS**: N-(tert-butyl)-N-(1-diethoxyphosphoryl-2,2-dimethylpropyl)-O-(1-methyl-1-(methoxycarbonyl)ethyl)hydroxylamine

- Mn_{th} targeted with MONAMS is $200\,000\text{ g.mol}^{-1}$

[0092] The results are recorded in Tables 1 (Example 2), 2 (Example 3) and 3 (Example 4) below.

[0093] In these tables, t (s) represents the polymerization time in seconds,

D_c the degree of conversion and

PI the polydispersity index, which is the ratio M_w/M_n .

t (s)	Dc	$\ln(1/(1-Dc))$	Mn(th)	Mn	Mw	PI
0	0	0				
300	0.09	0.094	63 00	5 700	10 500	1.84
1 800	0.32	0.385	22 400	23 600	31 800	1.35
3 600	0.52	0.729	36 300	35 200	44 400	1.26
6 300	0.72	1.272	50 400	44 300	56 400	1.27

TABLE 1: Results of Example 2

[0094] The results make it possible to plot the following kinetic curves associated with each example:

- $\ln(1/(1-Dc))$ as a function of the time; Mn(th), Mn and PI as a function of the degree of conversion Dc.

DESCRIPTION OF THE FIGURES

[0095] The kinetic curves corresponding to the results of Example 2 are represented in the following figures:

[0096] Figure 1: $\ln(1/(1-Dc)) = f(t)$;

[0097] Figure 2: Mn(th), Mn, PI = f(Dc)

t (s)	Dc	$\ln(1/(1-Dc))$	Mn(th)	Mn	Mw	PI
0	0	0				
720	0.05	0.048	9 400	35 500	50 500	1.42
1 200	0.11	0.116	22 000	47 500	66 300	1.40
2 400	0.25	0.287	50 000	74 500	108 900	1.46
3 300	0.53	0.755	106 000	86 300	148 700	1.72
6 000	0.62	0.967	124 000	89 700	172 000	1.92
8 400	0.79	1.560	158 000	96 800	168 100	1.74
9 600	0.80	1.609	160 000	110 900	177 200	1.60
12 600	0.82	1.714	164 000	141 800	220 700	1.56

TABLE 2: Results of Example 3

[0098] The kinetic results corresponding to the results of Example 3 are represented in the following figures:

[0099] Figure 3: $\ln(1/(1-Dc)) = f(t)$;

[0100] Figure 4: $M_n(th)$, M_n , $PI = f(T_c)$

t (s)	Dc	$\ln(1/(1-T_c))$	$M_n(th)$	M_n	M_w	PI
0	0	0				
600	0.06	0.060	12 000	27 700	38 400	1.39
1 500	0.13	0.139	26 000	53 900	94 900	1.76
2 700	0.24	0.274	48 000	66 600	106 800	1.60
3 600	0.56	0.820	112 000	88 900	130 800	1.47
5 400	0.65	1.049	130 000	104 200	155 800	1.50
7 200	0.71	1.237	142 000	100 500	190 600	1.60
10 800	0.75	1.386	150 000	103 300	177 600	1.72
13 200	0.76	1.427	152 000	113 900	198 300	1.74
19 800	0.79	1.560	158 000	105 800	264 800	2.50

TABLE 3: Results of Example 4

[0101] The kinetic curves corresponding to the results of Example 2 are represented in the following figures:

[0102] Figure 5: $\ln(1/(1-D_c)) = f(t)$

[0103] Figure 6: $M_n(th)$, M_n , $PI = f(T_c)$

[0104] The good alignment of the points on Figures 1, 2, 3 and 4 of the curves and the low polydispersity index (PI) are characteristics of a controlled radical polymerization of the butyl acrylate with the methylpropionic acid/SG1 alkoxyamine of the present invention.

[0105] **Example 5:**

[0106] Use of the methylpropionic acid/SG1 alkoxyamine as initiator in the copolymerization of methyl methacrylate (MMA) with butyl acrylate (BA)

[0107] Procedure:

[0108] The introduction was carried out of 0.953 g of methylpropionic acid/SG1 alkoxyamine, of 42.5 g of MMA and of 7.5 g of BA into a 100 ml glass reactor equipped with a reflux condenser, a jacket with circulation of oil, an inert gas (N_2) inlet and a temperature probe.

[0109] The medium was degassed by sparging with nitrogen for 20 minutes, then placed under mechanical stirring and brought to 95°C. Samples were withdrawn under an inert atmosphere at regular intervals.

[0110] Proton NMR allowed us to monitor the conversion of the monomer. The determination of the average molar masses of the polymer and of their polydispersity indices was carried out by SEC, using a universal calibration using poly(styrene) standards and the Mark-Houwink coefficients of poly(butyl acrylate) in THF.

[0111] The results are recorded in Table 4 below.

[0112] In this table:

- Dc BA means degree of conversion of the butyl acrylate,
- Dc M means degree of conversion of the methyl methacrylate,
- Dc O means overall degree of conversion

t (s)	Dc BA	Dc M	Dc O	$\ln(1/1-Dc BA)$	$\ln(1/1-Dc M)$	$\ln(1/1-Dc O)$	Mn	PI
900	0.11	0.23	0.22	0.11	0.27	0.24	10 40 0	1.47
2 10 0	0.15	0.32	0.30	0.16	0.38	0.35	13 50 0	1.37
3 30 0	0.17	0.38	0.35	0.19	0.48	0.43	14 70 0	1.41
5 70 0	0.25	0.48	0.45	0.28	0.66	0.60	16 20 0	1.38
9 00 0	0.30	0.74	0.67	0.35	1.35	1.12	17 80 0	1.37

TABLE 4: Results of Example 5

[0113] The results carried in Table 4 make it possible to plot the kinetic curves which are represented in the following figures:

[0114] Figure 7: $\ln(1/1-Dc BA) = f(t)$;

[0115] Figure 8: $\ln(1/1-Dc M) = f(t)$;

[0116] Figure 9: $\ln(1/1-Dc O) = f(t)$;

[0117] Figure 10: $Mn = f(Dc O)$;

[0118] Figure 11: $PI = f(Dc O)$.

[0119] **Example 6:**

[0120] The operation is carried out as in Example 5, except that the copolymerization is carried out at 120°C (instead of 95°C) and that 0.0368 g of nitroxide SG1 is added.

[0121] The results are recorded in Table 5 below.

t (s)	Dc BA	Dc M	Dc O	$\ln(1/1-Dc\ BA)$	$\ln(1/1-Dc\ M)$	$\ln(1/1-Dc\ O)$	Mn	PI
900	0.11	0.18	0.17	0.12	0.20	0.24	19 700	1.15
2 100	0.05	0.27	0.24	0.05	0.32	0.35	26 300	1.23
3 300	0.17	0.31	0.29	0.19	0.37	0.43	37 500	1.20
4 500	0.13	0.33	0.30	0.14	0.41	0.60	46 400	1.23
8 100	0.15	0.48	0.43	0.16	0.65	1.12	61 600	1.22
10 200	0.26	0.62	0.56	0.31	0.97	1.12	71 300	1.24

TABLE 5: Results of Example 6

[0122] The results carried in Table 5 make it possible to plot the kinetic curves which are represented in the following figures:

[0123] Figure 12: $\ln(1/1-Dc\ BA) = f(t)$;

[0124] Figure 13: $\ln(1/1-Dc\ M) = f(t)$;

[0125] Figure 14: $\ln(1/1-Dc\ O) = f(t)$;

[0126] Figure 15: $Mn = f(Dc\ Overall)$;

[0127] Figure 16: $PI = f(Dc\ Overall)$.

[0128] **Examples 7 et 8:**

[0129] Use of the methylpropionic acid/SG1 alkoxyamine as initiator in the polymerization of methyl methacrylate (MMA)

[0130] **Procedure:**

[0131] 10 g of MMA and 198 g of methylpropionic acid/SG1 alkoxyamine are mixed in a 25 ml two-necked round-bottomed glass flask. The mixture is placed under a nitrogen atmosphere by carrying out 3 reduced pressure/nitrogen cycles, stirred (magnetic stirring) and subsequently brought to a predetermined polymerization temperature.

[0132] **Example 7:**

- Polymerization temperature: 25°C

[0133] The results are recorded in Table 6 below.

[0134] In this table, Dc M means degree of conversion of the methyl methacrylate.

Time (hours)	Dc M	Mn	PI
2	0.13	11 800	1.9
4	0.14	12 900	1.8
21	0.16	14 800	1.7
29	0.18	17 500	1.6
45	0.20	19 600	1.5
69	0.22	20 700	1.4

TABLE 6: Results of Example 7

[0135] **Example 8:**

- Polymerization temperature: 45°C

[0136] The results are recorded in Table 7 below.

[0137] In this table, Dc M means degree of conversion of the methyl methacrylate.

Time (minutes)	Dc M
15	0.24
30	0.34
45	0.39
90	0.55
135	0.68

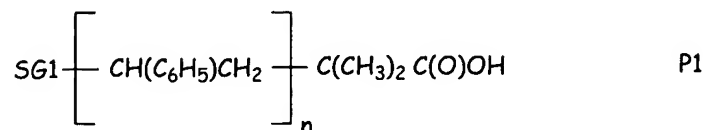
TABLE 7: Results of Example 8

[0138] **Example 9:**

[0139] Polymerization of styrene in the presence of the methylpropionic acid/SG1 alkoxyamine according to the present invention

[0140] 30 g of styrene (0.288 mol) and 1.143 g of methylpropionic acid/SG1 (3 mmol) are placed in a three-necked flask equipped with a reflux condenser and a magnetic stirrer. The solution is degassed by sparging with nitrogen for 20 minutes. The reaction mixture is heated to 123°C. The progress of the polymerization is monitored by ¹H NMR on samples withdrawn every 30 minutes. At the end of the reaction (the duration of polymerization is 5h 30), the polymer is dissolved in THF and then precipitated from pentane.

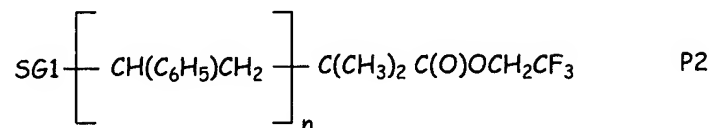
[0141] The polymer is recovered by filtering the solution and then dried on a vacuum line. 24 g (yield: 90%) of a polymer P1 are obtained, which polymer has the structure:



with a molecular mass \overline{Mn} approximately equal to 10 000.

[0142] **Example 10:**

[0143] Synthesis of a polymer P2 with the structure:



5 g of polymer P1 obtained above in Example 9 (0.45 mmol) and CH_2Cl_2 are introduced into a two-necked flask equipped with a stirring system and a septum. The solution is degassed by sparging with nitrogen for 10 minutes.

[0144] 0.34 ml of SOCl_2 (4.8 mmol) is introduced through the septum using a syringe.

[0145] The mixture is stirred at ambient temperature under an inert atmosphere for 2 hours.

[0146] The solution is subsequently concentrated on a reduced pressure line (pressure of 10^{-1} mbar) to evaporate the CH_2Cl_2 and excess SOCl_2 .

[0147] The two-necked flask is placed under nitrogen and then THF, capable of dissolving the polymer $\text{SG1}[\text{CH}(\text{C}_6\text{H}_5)\text{-CH}_2]_n\text{C}(\text{CH}_3)_2\text{C}(\text{O})\text{Cl}$, is added thereto, followed by a solution comprising 0.13 ml of triethylamine and 0.122 g of 4-dimethylaminopyridine (DMAP) (1 mmol) and then 0.34 ml of $\text{CF}_3\text{CH}_2\text{OH}$ (4.80 mmol) in THF.

[0148] The immediate appearance of a white precipitate is noticed. The reaction medium is stirred for approximately 2 hours at ambient temperature. The precipitate is removed by filtration and then the filtrate is evaporated under reduced pressure.

[0149] The polymer P2 obtained is purified by dissolving in THF and then reprecipitated from pentane. The product is subsequently filtered off and dried on a reduced pressure line. 5.01 g of P2 are obtained.

[0150] Analytical characteristics:

[0151] ^{19}F NMR (CDCl_3 , 282.4 MHz): $\delta = 74.02$ ppm

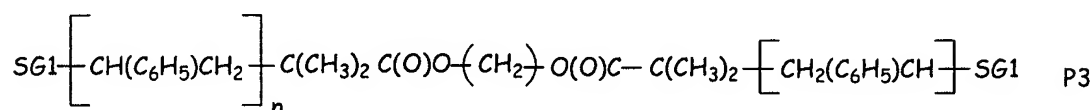
[0152] ^{31}P NMR (CDCl_3 , 121.49 MHz):

$\delta = 25.61$ ppm (singlet) (1 dia. 67%)

$\delta = 24.43$ ppm (singlet) (1 dia. 33%)

[0153] **Example 11:**

[0154] Synthesis of a polymer P3 with the structure:

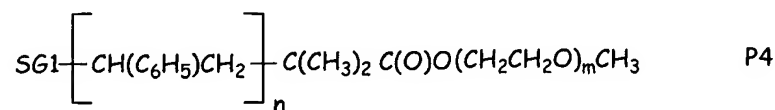


[0155] The operation is carried out as in Example 10 above, except that 0.5 equivalent of ethanediol is used instead of 4.80 mmol of $\text{CF}_3\text{CH}_2\text{OH}$ and that, in the first stage (formation of the acid chloride), the reaction medium is brought to 40°C for 2h and that, in the following stage [coupling stage], the reaction medium is brought to ambient temperature for 16h.

[0156] The degree of coupling, determined by GPC, is 47%.

[0157] **Example 12:**

[0158] Synthesis of a polymer P4 with the structure:



by coupling between the polymer P1 and a PEO-OMe block ($\overline{Mn} = 750 \text{ g.mol}^{-1}$)

[0159] Procedure:

[0160] P1, dissolved in THF, is placed in a two-necked flask equipped with a stirring system and a septum. The solution is degassed by sparging with nitrogen for 10 minutes. Thionyl chloride (10 equivalents) is introduced through the septum using a syringe. The mixture is stirred under an inert atmosphere for 4 hours at 40°C. The solution is subsequently concentrated on a reduced pressure line to evaporate the solvent and the excess thionyl chloride.

[0161] A solution of triethylamine (1 equivalent), of 4-dimethylaminopyridine (DMAP) (catalytic) and of the PEO-OMe block (3 equivalents) in DMF is then added to the two-necked flask placed under nitrogen. The mixture is stirred for 17 hours at 80°C.

[0162] P4 and P1 are separated from the excess PEO-OMe by selective precipitation from ethanol, filtered off and then dried on a vacuum line. The degree of coupling, determined by proton NMR, is 7%.

[0163] Example 13:

[0164] Synthesis of the polymer P4 using dicyclohexylcarbodiimide (DCC) instead of triethylamine without passing through the acid chloride stage

[0165] Procedure:

[0166] P1 (1 equivalent), α -methoxylated-poly(ethylene oxide) (1 equivalent) and 4-dimethylaminopyridine (DMAP) (0.8 equivalent) are placed in anhydrous dichloromethane in a round-bottomed flask equipped with a magnetic stirrer and a reflux condenser. The solution is degassed by sparging with nitrogen for 10 to 15 minutes. Dicyclohexylcarbodiimide (DCC) (2.6 equivalents), dissolved in the minimum amount of CH_2Cl_2 , is added to the mixture using a syringe.

[0167] The mixture is left to stir at ambient temperature for 24 hours.

[0168] Subsequently, P4 and P1 are separated from the excess PEO-OMe by selective precipitation from ethanol, filtered off and then dried on a vacuum line. The degree of coupling, determined by proton NMR, is 38%.